REVIEW OF THE WINDMILL PITCH: BIOMECHANICS AND INJURIES

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ABSTRACT

Objective: To review the literature of the biomechanics of the windmill fast-pitch and its implications for injury. This information may be utilized in treating youth windmill pitchers.

Data Source: A MEDLINE search was conducted to retrieve articles regarding the windmill pitch. Key terms were then taken from the pilot search and used to conduct a systematic search and review of the literature.

Results: Articles containing information on the windmill pitch and injuries associated with the motion were reviewed. Additional information pertaining to the overhand baseball pitch and overuse injuries in youth were analyzed and synthesized into the body of information.

Conclusion: A complex sequence of actions is required to successfully perform the windmill pitch. Overuse injuries are common in windmill pitchers. A well-designed conditioning schedule and the regulation of the frequency and volume of pitching in youth fast-pitch may assist with managing injury associated with this activity. Further investigation of specific treatment methods is needed. (J Chiropr Med 2004;3:53–62)

Key Indexing Terms: Biomechanics; Underhand Pitching; Softball; Chiropractic; Shoulder; Elbow

INTRODUCTION

Interest in this project developed as a result of my participation as team physician with local select young women's fast-pitch softball teams. Injuries developed with the pitchers that appeared to be chronic in nature. According to the Amateur Softball Association, in the 2002–2003 school year, fast-pitch softball had the third greatest increase in participation, now ranking it the fourth most common sport offered at the high school level (1). Despite increasing participation in fast-pitch among young women, historically little research has been done on the windmill pitching style. Initially, the consensus was that injury potential was low because the motion appeared seemingly effortless (2–6). Although recent literature suggests that overuse injuries are prevalent, controversy regarding this matter still exists.

Articles describe kinetics, kinematics, biomechanics and injuries associated with the unique windmill pitching style. Existing research has primarily focused on elite pitchers, illustrating that the forces produced with the windmill motion are similar to the overhand throw (3,5). Based on this correlation with the overhand throw, studies of baseball pitchers' delivery were investigated.

The purpose of this paper is to integrate the information into a summary of the mechanics of the windmill pitch, correlate this motion to the injury potential to young women, and provide potential treatment and prevention options.

METHODS

Literature searches were completed through MEDLINE and MANTIS. The initial search for recent literature began with MEDLINE (1995–2002) using the terms *windmill pitch*. Two articles were found and became the core and catalyst for the remaining research. Based on key words found in the original articles, various search terms were selected and used to continue to search the literature.

The search was broadened using the terms *shoulder, injury, biomechanics, softball* and *pitching;* in addition to combining phrases such as *underhand pitching, windmill pitch* and *fast-pitch softball injuries*. Additional searches through MEDLINE (1980–2003) and MANTIS were investigated and cross-referenced. The following web addresses were also accessed: www.ajsm.com, www.asmi.com and www.asasoftball.com. Articles were included in this review if they were published in English and discussed mechanics or injuries associated with the windmill fast-pitch delivery. Following the search, retrieval and analysis of the cited literature, other the literature searches were undertaken. These focused on the overhand baseball pitch and overuse injuries in youths. A research synthesis resulted in conclusions and recommendations offered.

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DISCUSSION

The fast-pitch windmill motion appears straightforward. Many have thought that this seemingly natural motion results in minimal stress on the glenohumeral joint (2–6) and the surrounding dynamic and static stabilizers. The lack of literature on this topic is mentioned in the earlier studies by Loosli et al, Maffet et al and Barrentine et al. Growing interest in this topic is a result of increasing participation in this sport, particularly with the introduction of Women's Fast-pitch to the 1996 Olympic Games, in addition to the increasing concern for injuries resulting from this motion.

The following sections outline the kinematics (the study of motion, without taking into account the forces which act to generate the motion); the specific muscle firing patterns, as illustrated by Maffet et al, and their association with each specific phase; and kinetics (the study of the forces that act on motions of a body to accelerate or decelerate the body) as described by Barrentine et al. Incidence of injury will also be reviewed.

Alexander and Haddow examined and reported on the kinematics of the windmill pitch (7). These early investigations provided a foundation for subsequent research. They explored the windmill pitch and relative motions of the upper arm, lower arm and hand in four highly skilled pitchers; two male and two female. Data were gathered from the sagittal plane then digitized and analyzed. Angular position, angular velocity and angular acceleration were plotted against time for each body segment (hand, lower arm, upper arm).

Alexander and Haddow concluded "there was a definite proximal-to-distal sequence of these motions, with decelerations occurring in the proximal segments, prior to ball release." Their findings confirmed previous results of earlier studies by Plagenhoef and Atwater. Alexander and Haddow theorized that there was a "transfer of momentum" to the distal segment with the deceleration of the proximal segment, which tends to "increase the angular velocity of the distal segment (and) since the distal segments trail the proximal segments for the first part of most ballistic movements, due to the inertia of these segments, this puts the agonist muscle groups on stretch" (7) thus facilitating the stretch reflex and resulting in a more vigorous contraction (7,8). These findings implicate this as a possible mechanism of injury in addition to documenting the importance of proper sequencing.

Barrentine et al focused on kinematics and kinetics of the windmill pitch and then compared these forces to the overhand pitch. Kinetics encompasses Newton's first and third law of inertia. The first law states that a body at rest tends to stay at rest and a body in motion tends to stay in motion. The third law states that for every action, there is an equal and opposite reaction. The findings approximate what is found in the overhand pitch. This data, in conjunction with the injury reports by Loosli et al and Barrentine et al, suggest that the strain on the shoulder joint is analogous to the overhand throw. In reporting the similarities of these actions, inferences from baseball can be made and applied to the windmill pitch.

The Windmill Motion and Its Implications for Injuries

Maffet et al delineates the specific muscle firing patterns of the following muscles during the windmill pitch: supraspinatus, anterior deltoid, posterior deltoid, infraspinatus, teres minor, pectoralis major, subscapularis, and serratus anterior muscles. Using fine-wire intramuscular electrodes, electromyography (EMG) was performed to analyze muscle contractility. While inserted, each muscle was manually tested for maximum strength, representing 100% muscle activity. Figures 1–3 demonstrate the relative contributions of these muscles based on their percent of maximum muscle testing (MMT). The contributions of these muscles are outlined in the various phases of the windmill pitching motion.

The Windmill Motion

The circumferential motion of the upper extremity has been described differently in the literature by various researchers (3,5). Maffet et al divided the motion into six phases based on the face of a clock as the motion travels counterclockwise (Figure 4). This classification

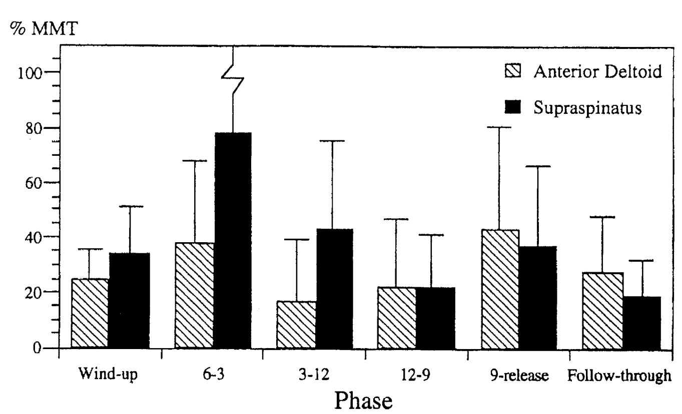

Figure 1. Percent MMT of anterior deltoid and supraspinatus muscles by phase. Maffet et al, Shoulder muscle firing patterns during the windmill softball pitch (AJSM Vol 23 No 3) pp. 369–374, copyright (©) 1997 Reprinted by permission of Sage Publications.

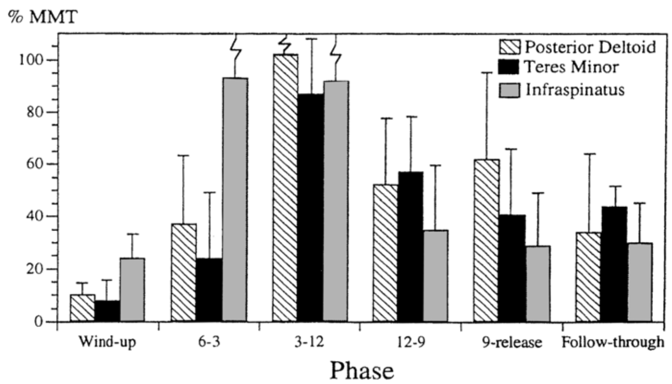

Figure 2. Percent MMT of posterior deltoid, teres minor, and infraspinatus muscles by phase. Maffet et al, Shoulder muscle firing patterns during the windmill softball pitch (AJSM Vol 23 No 3) pp. 369–374, copyright (©) 1997 Reprinted by permission of Sage Publications.

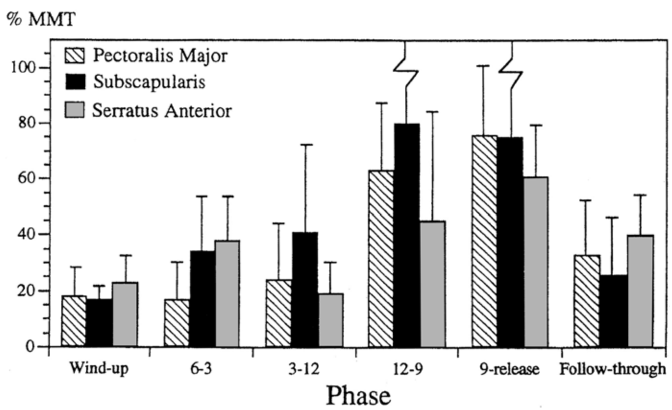

Figure 3. Percent MMT of pectoralis major, subscapularis, and serratus anterior muscles by phase. Maffet et al, Shoulder muscle firing patterns during the windmill softball pitch (AJSM Vol 23 No 3) pp. 369–374, copyright (©) 1997 Reprinted by permission of Sage Publications.

was utilized after observing specific characteristics of the firing patterns of the individual muscles. The separation of the phases into 90-degree progressions simplified the categorization of the muscular contributions. It begins with the wind-up and ends with the follow-through. The core of the motion are named phases 2 through 5. These were illustrated as follows: phase 2, 6 to 3 o'clock; phase 3, 3 to 12 o'clock; phase 4, 12 to 9 o'clock; and phase 5, 9 o'clock to ball release.

To simplify the analysis of their data, Barrentine et al used the terms: "wind-up" (a-c), "stride" (d-f), "delivery" (g-j) and "follow-through" (k-l) as depicted in Figure 5. Inspection of this series reveals gaps between the groupings, whereas Maffet et al demonstrate continuity between the phases. In the analysis below, the classification suggested by Barrentine et al and the one used by Maffet et al are compared. Any descriptions that follow are designated for a right-handed pitcher.

The Wind-Up

Barrentine et al depicts wind-up as the "time from initial movement from the ready position until the lead foot (stride foot) toe-off," closely corresponding to the initial movement in Maffet et al. The wind-up ends at the 6 o'clock position. Commonly the style of wind-up can vary significantly from pitcher to pitcher, (5) incorporating variations in trunk flexion, hip rotation and elbow extension (5,8). There is a weight shift back to the stride foot, left for a right-handed pitcher, and then forward onto the pivot foot (8,9). As the pitcher pushes off the pitching rubber to begin forward translation, the shoulder is hyperextended (3,8).

The kinematic and kinetic parameters are small throughout the stride phase[3] and according to Maffet et al, during this phase the muscle activity is minimal (overall less than 34% of maximum). The main muscle activity of the shoulder, in decreasing intensity, is: anterior deltoid, supraspinatus, infraspinatus and serratus anterior. The key action of the anterior deltoid and supraspinatus muscle is to initiate the forward flexion of the shoulder (5).

The Stride

The stride, as described by Barrentine et al, is "the time from lead foot toe-off to lead foot contact (foot flat) with the ground." This encompasses (approximately) the 6 o'clock to about 12 o'clock position as depicted by Maffet et al. As the weight shifts from the stride foot to the pivot foot, the pivot foot turns toward third base and the stride foot extends forward, resulting in linear velocity of the pelvis (3). It is imperative that the stride foot maintains a line toward the target and lands within a 30-degree range of internal rotation[10] and the knee remains flexed so it can absorb shock. As the stride leg plants, eccentric contraction of the quadriceps muscle of that leg further minimizes shock (8). According to Sammons, there are variations in basic footwork (9): "[1] timing of the push off the pitchers plate; [2] energy of the push off the pitcher's plate; and [3] length of the stride off the pitcher's plate."

During the first half of the stride, the arm is elevated from the 6 o'clock to the 3 o'clock position with the shoulder internally rotated. At the end of this phase, the

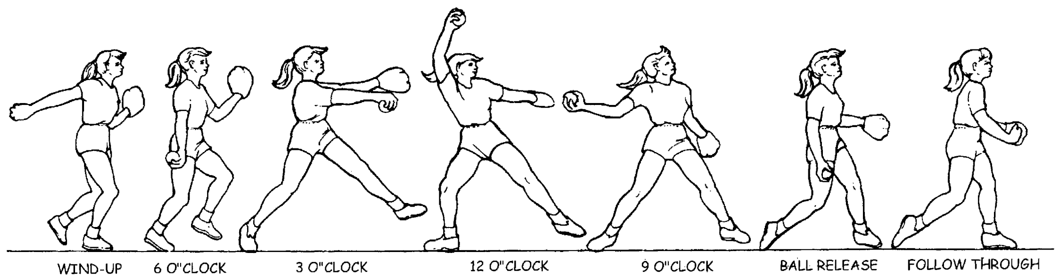

Figure 4. Six phases of the windmill pitch. Maffet et al, Shoulder muscle firing patterns during the windmill softball pitch (AJSM Vol 23 No 3) pp. 369–374, copyright (©) 1997 Reprinted by permission of Sage Publications.

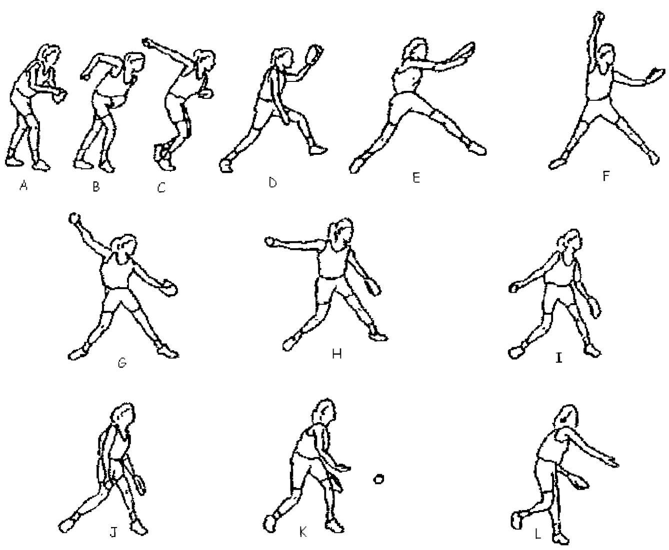

Figure 5. Sequence of motion in windmill pitching. (Barrentine et al 1998)

12 o'clock position, the torso has opened up toward third base and the humerus is extended to approximately 180 degrees (3) and externally rotated. This is a critical position that allows the upper extremity to revolve in the plane of the body (5,9).

In the first half of the stride, described as phase 2 (6 o'clock to 3 o'clock) by Maffet et al, it was determined that the activity of the infraspinatus and the supraspinatus muscles spikes to its highest firing, peaking to 93% ± 52% MMT and 78% ± 36% MMT respectively. These muscles work in opposite directions as a force couple (11). Their role is to set the humeral head in the glenoid, preventing superior migration of the humeral head as the deltoid engages (5,11). Of all the muscles tested, the anterior deltoid had the smallest EMG firing. In the 6 to 3 o'clock phase, the activity of this muscle was 38% ± 29% MMT.[5] (Its activity peaked once more during phase 5, 9 o'clock to ball release, but only to 43% ± 38% MMT).

The activity of the posterior deltoid is at an all-time high in the latter half of the stride, phase 3 (3 o'clock to 12 o'clock),[5] (102% ± 42% MMT), followed by the infraspinatus and teres minor muscles (92% ± 38% MMT and 87% ± 21% MMT respectively). These muscles act to externally rotate the humerus.

The Delivery

The delivery phase was identified "as the time from [stride] foot contact to ball release" (3) and includes, phases 4 and 5 of Maffet's description: 12 o'clock to ball release. During these phases, the upper extremity begins the downward motion of the circle, accelerating the arm and ball forward, as the torso and pelvis rotate to a closed position. Transferring the kinetic energy from the lower extremities generates additional power to the pitch (8,9). The highest peaks for kinematic and kinetic parameters take place at this time (3).

According to Barrentine et al, there is a maximum torque of adduction and internal rotation at the shoulder noted during the first half of the delivery phase, estimated at 12 o'clock to 9 o'clock. These investigators report a maximum angular velocity of more than 5000 degrees per second as the shoulder flexes forward (3). These kinematic values correspond with firing patterns generated by the pectoralis major and subscapularis muscles (5). The subscapularis muscle's prime activity (81% ± 52% MMT) is to assist the pectoralis major in internal rotation and protect the anterior capsule (5). Meanwhile the pectoralis major (63% ± 23% MMT) and serratus anterior (45% ± 39% MMT) firing patterns increase significantly while working in tandem as a force couple. The teres minor and posterior deltoid contributions decrease to a more modest intensity that is maintained through ball release.

In the second half of the delivery (phase 5, Maffet et al, beginning at 9 o'clock and ending at ball release), the pectoralis major muscle has the majority of its firing

(76% ± 24% MMT) followed by the subscapularis (75% ± 36% MMT), posterior deltoid (62% ± 29% MMT) and serratus anterior (61% ± 19% MMT).[5] The serratus anterior is at its highest activity at this point acting to stabilize the scapula as it opposes the strong pectoralis major muscle. According to Barrentine et al, adduction and forward flexion of the shoulder result in a maximum medial force (74% body weight [BW]) and maximum anterior force (38% BW) at the shoulder during the middle of delivery (3).

The latter part of the delivery is also characterized by maximum pelvic and upper torso rotation (3). Subsequently, as the forearm lags behind the shoulder, a maximum extension velocity of 570 degrees per second is achieved at the elbow (3). This results in a maximum flexion torque at the elbow which translates into a maximum compressive force of 70% BW at the elbow.

Internal rotation of the humerus dominates the activity during the latter quarter of the delivery phase (3). This is achieved by the pectoralis major and subscapularis muscles, which generate the major power for the delivery (5). The maximum superior compressive forces of 98% BW are attained at the shoulder at this crucial time (3), while Werner et al report an average shoulder distractive load of 80% BW.[10] These quantities compare to the peak values of shoulder distraction in the baseball throw which reaches 83 to 139% BW.[12] There is a maximum velocity of 4600 degrees per second at the shoulder representing the internal rotation velocity (3). Additionally, these investigators state that a maximum torque is attained at the shoulder with abduction (9% BW ×HT [Height]) and extension (10% BW ×HT). While at the elbow a maximum lateral force of 47% BW and maximum valgus torque (4% BW ×HT) was recorded. Distractive forces, which affect the joint to control the centrifugal forces of the motion, also work to restrain internal rotation of the shoulder and extension of the elbow (3).[1]

The Follow-Through

The follow-through begins at ball release. Windmilling speed at ball release among 24 pitchers of the 1996 Olympic Games averaged 1885 degrees per second (10). Deceleration of the arm and forearm occur following ball release. Maffet et al maintain that the strain on the teres minor is lessened because of the dampening effect when the pitching arm contacts the lateral thigh. Barrentine et al dispute this theory by determining that the average torque to the shoulder at this moment was equal to approximately 100 Newton-meters (73.7562 foot-pounds).

Following the release of the ball, Barrentine et al further detail the forces acting upon the shoulder and elbow noting, "A second peak extension torque (9% BW ×HT) was exerted and a maximum posterior force (59% BW) was experienced at the shoulder. During the follow through phase, a second peak elbow compressive force occurred (56% BW) as a maximum extension torque (2% BW ×HT) was exerted. A maximum elbow flexion velocity (880 degrees/sec) was reached as the forearm continued to decelerate" (3). While much of the muscle activity is decreased during this deceleration phase, the teres minor (44% ± 11% MMT) and serratus anterior (40% ± 14% MMT) muscles report the highest level of activity (5).

Windmill Pitch versus Baseball Pitch

Although, on the surface, the windmill pitch appears completely different than the baseball pitch, similarity in joint forces and muscle actions have been demonstrated (3,5). The similarities of muscle contributions to the baseball pitch determined by Maffet et al are as follows: (1) the "pectoralis major muscle is the main power generator of the shoulder; (2) the stabilization against anterior forces is accomplished by anterior wall muscles (subscapularis and pectoralis major); (3) (and) the serratus anterior muscle acts as a scapulohumeral synchronizer." Barrentine et al alternatively did a qualitative analysis of the forces or loads on the shoulder and elbow joints, taking into consideration the social and gender differences between men and women. Recognizing the strength differences between men and women and dissimilarities among the frequencies of pitching, they note that the windmill pitch demands resistance to the centrifugal forces while simultaneously controlling internal rotation and elbow extension.

Maffet et al were the first to document the differences between the baseball pitch and the windmill pitch. According to these investigators, during the baseball pitch, the humerus is abducted, whereas in the fast-pitch underhand throw, the humerus is in the plane of the body. According to Meister (13), the biomechanics of the windmill motion "eliminates the significant contribution of the posterior cuff musculature in both the acceleration and deceleration phases" (eg, delivery and follow-through). In addition, internal rotation of the humerus contributes to the power of the baseball pitch while adduction across the body contributes to the power of the windmill pitch (5). The primary muscle driving these motions, internal rotation or adduction, is the pectoralis major muscle while the antagonistic serratus anterior muscle stabilizes the scapula. And lastly, the baseball pitch is decelerated by eccentric muscle control of posterior shoulder muscles, particularly the teres minor and Maffet et al affirm that deceleration of the arm occurs because of contact with the hip thus reducing the risk of injury to this muscle.

Injuries

Forces and Injury Potential

The distractive forces on the shoulder at ball release are intensified by the increased weight of the softball (as compared to the baseball) (3) and increased extension of the elbow amplifying the centrifugal forces. Barrentine et al report a peak distractive force equivalent to 98% BW, whereas Werner et al, in a study of 24 Olympic pitchers, reported a range of 50% to 150% body weight. The critical instance of maximum distraction occurs during the delivery of the windmill pitch approaches 80 to 95% of the values established for the baseball pitch (3,10). It is at this point where the athlete is at greatest risk of injuring the subscapularis or pectoralis major muscle. At the start of this phase, these muscles are in a stretched position as the muscle activity increases dramatically to accelerate the arm and ball (3). These muscles can result in anterior shoulder pain, which is the most common complaint.

Similar distractive forces on the elbow were identified, attaining 67 to 79% values of the baseball pitchers (3). The investigators report: "Forces to resist distraction reach a peak at a time during delivery that elbow flexion torque is exerted to control elbow extension and initiate elbow flexion. The demand on the biceps labrum complex to both resist glenohumeral distraction and produce elbow flexion torque makes this structure susceptible to overuse injury. Internal rotation of the humerus and pronation of the forearm further complicate the mechanism" (3). These investigators also note that injury can occur as the medial elbow contacts the hip causing ulnar neuritis.

The second most common complaint is posterior shoulder pain (3). The posterior shoulder muscles (posterior deltoid, infraspinatus and teres minor) are injured while contracting eccentrically to decelerate the upper extremity. The integrity of these dynamic stabilizers is jeopardized with injury resulting in dysfunction and possibly increased anterior instability. Joint laxity can be a risk factor associated with injury (3,4,14). Kocher et al note that there is an increasing frequency of multidirectional instability, posterior subluxation and recurrent subluxation being identified in adolescent throwers (14). A recent study in 2003 by Dover et al concluded that there was an increase in injury potential in asymptomatic female athletes involved in overhand sports due to decreased shoulder proprioception (15).

Cumulative Injury Disorder

Leahy describes overuse or cumulative injury disorder (CID) as a group of injuries occurring to the muscles, tendons, bones, blood vessels, fascia and/or nerves (16). This can occur from acute injury, repetitive injury or a constant pressure or tension on the tissue. Leahy establishes that the "insult (I) to the tissue approximates the number (N) of repetitions multiplied by the force (F) or tension of each repetition as a percent of maximum muscle strength divided by the amplitude (A) of each repetition multiplied by the relaxation (R) time between repetitions [I ≈ NF/AR]." It is noted that competitive female fast-pitch pitchers, during a tournament, commonly play two days in a row and probably multiple games during a day (2–4,6) whereas, the starting baseball pitcher has three to four days of rest between games. Acknowledging the equation above, one may consider that this frequency of play in conjunction with the minimal rest periods is an important contributor to potential overuse injuries in female fast-pitch players.

Figure 6 demonstrates the causes and the effects to each part of the cumulative injury cycle (16). The cycle illustrates, with an acute injury, tearing or crushing of the affected tissue ensues, and thereby creating an inflammatory response that sets up the foundation for adhesions and fibrosis, resulting in a weak and tense tissue. These weak and tense tissues create friction, pressure and tension thereby perpetuating the cycle.

Repetitive-strain injury cycle begins as weak and tense tissue or by increased friction and pressure. If the force is high enough it can result in inflammation or decreased circulation or edema in the chronic state. Both of these end-products result in adhesion and fibrosis, thus causing weak and tense tissues. Similar conse-

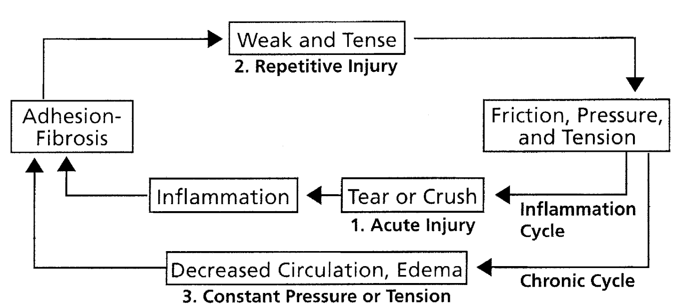

Figure 6. The cumulative injury cycle. Reprinted with permission from Active Release Techniques, LLC.

quences are noted with the constant pressure or tension scenario (16).

Injuries and Adolescents

Literature relating to the overhand pitch documents the experience of professional baseball pitchers (3,5,6,17). The recent focus on overuse injury with youth has mainly been on Little League Baseball (14,18–21). With the emphasis on specialization in sports, many youth are asked to pick one sport to be their focus. One noteworthy study by Fleisig et al compared the kinematics and kinetics between youth, high school, college and professional baseball pitchers. They studied 231 baseball pitchers from age 10 to 29-years-old. Although these investigators reported a direct relationship between joint forces and torque and increasing skill level, they noted that there was no difference in the pitching mechanics between the various maturity levels.

Recently, new information has been published on the topic of the risk of elbow and shoulder pain in youth baseball pitchers (20,21). Two studies by Lyman et al looked at pitchers (9) to 14-years-old, to evaluate the frequency of elbow or shoulder complaints and to correlate these complaints with pitch type, pitch volume and other risk factors. Participants were contacted after each game and a pitching log was kept. The authors concluded that pitch type and pitch count contributed to shoulder and elbow pain, more commonly from overuse or an "accumulation of micro-trauma from the repetitive pitching motion" (20). This study was detailed and comprehensive to all aspects of pitching. It was the first study of its kind to contemplate the risk of various pitches to shoulder or elbow pain.

Recommendations for youth baseball resulting from these studies included: limiting pitchers to 75 pitches per game or 600 pitches per season, or alternatively capping the number of batters pitched to 15 per game or 120 per season; age adjustments for pitch type, no curve ball or slider between the ages of 9 to 14; limiting play to one league at a time or reducing the pitches in non-league games; and educating pitchers and coaches on proper strength and conditioning programs.

A similar study was performed in 2002 by Fleisig et al where 321 female pitchers completed a survey that encompassed the prior year of play (6). Their ages ranged from 8 to 23 (2). years old with an average age of 13.8 years. Many started playing organized softball at an average age of 7.2 years (3 to 15-year-old range) and began pitching at an average age of 9.8 years (5 to 16-year-old range). The average pitcher played in more than 3 leagues. Average number of pitches thrown throughout the year was 4,300 with a low of 175 pitches to a high of 28,000, significantly higher than their baseball counterparts. The authors compared their data to pitching injury reports from Loosli et al and Lyman et al (2,20,21). Although the investigators recognized that due to the retrospective nature of their study inaccuracies may have occurred when estimating the volume of pitching, they concluded: overuse injuries of the shoulder and back are common and result in time loss (6). In addition, these investigators understand the importance of whole body conditioning to aid in maintaining proper biomechanics, thus reducing the risk of overuse.

Adolescents are also susceptible to overuse injuries (13,14,19–21). Kocher et al documented the escalating number of injuries associated with increasing numbers of participants and level of competition (14). Furthermore, young athletes today feel the pressure to specialize in one particular sport, due in part to the overlap of athletic seasons and fueled with the of hopes of a college scholarship. This practice decreases any cross-training effect from participating in a variety of activities. According to Carson et al, after reviewing the cases of 23 Little Leaguer's shoulder problems, 65% of the cases had played baseball for more than 12 months and conclude that the etiology is due to overuse (19). They note that during growth spurts, there is an increase in activity at the growth plate (physis) whose structure is weak and vulnerable to injury.

The data support the notion that similar biomechanics are evident in youth and adult pitchers, thus the joint stresses occurring in youth pitchers are comparable to the adult, however to a lesser degree (13,17). Meister states that "many of the same overuse conditions seen in the adult population may be seen in preteen and young adolescent: rotator cuff tendonitis, biceps tendonitis, and capsular strains." This conclusion supports that practicing fundamentals and biomechanics are the key to longevity and injury prevention.

Fast-pitch Studies

Earliest reports of injuries were noted in a study done by Tanabe et al (22). Three cases of fatigue fracture of the ulna of fast-pitch softball pitchers were documented. All cases were males aged 16 to 20 years. The duration of training was from 2 to 6 years. To study this phenomenon they analyzed the motion of 6 healthy well-trained pitchers, 3 male and 3 female. Their example of the windmill delivery shown in this study reveals a slight flexion of the elbow throughout the wind-up just prior to release. They note that the wrist is "dorsally flexed at the moment of releasing the ball" (22). This finding is confirmed by Olson and Hunter (8). In addition, at the follow-through, these researchers noted that not only did the shoulder appear to be maximally internally rotated, but the forearm was at maximum pronation and the wrist flexed. CT scans of the healthy subjects established that the middle one-third of the ulna was the most vulnerable. They concluded that the etiology of this injury was due to repeated torsion of the more mobile radius acting upon the relatively restricted ulna, in conjunction with the inherent weakness from the general narrowing of the ulna in mid shaft (22). Also contributing was that cancellous and cortical bone does not respond well to shear stress.

In 1989, Loosli et al surveyed pitchers from 8 of the top 15 NCAA teams for injuries sustained during the 1989 season (2). Twenty-four pitchers were investigated. In addition to reported injuries, details on approximate innings pitched and NSAID use was noted. The survey revealed that approximately 46% of the participants had an injury that resulted in time loss. Of the injuries resulting in modified play or time loss, 82% involved the upper extremity. Also of interest was the fact that 46% of the pitchers took NSAIDs regularly throughout the season (2). It was undetermined as to whether the medication was taken for pain management or prophylaxis.

Meyers et al reported on 10 NCAA teams, including fielders and pitchers, from 1975 to 1978 (4). Ten percent of the practice injuries were attributed to pitching and 12% of game injuries were the result from pitching. They correlated these injuries to repetitive microtrauma from overuse identifying factors such as age and experience, physical demands, and over-training.

In addition, there are two reports of "windmill pitcher's radial neuropathy" described by Sinson et al (23). Relevant is a report of a 16-year-old female who presented with a 10-month history of weakness in her dominant upper extremity and hand. According to the article, she initially recalled posterior arm soreness with pitching, which progressed into weakness within weeks. EMG revealed "severe radial nerve palsy involving the triceps and all distal muscles innervated by the radial nerve" (23). Exploratory surgery revealed a "16 cm. fusiform neuroma" of the posterior cord with the diameter about 3–4 times its normal size. The researchers surmise that the etiology of this lesion was a combination of traction on the nerve caused by the centrifugal forces in conjunction with a narrowed fibrous arch of the lateral head of the triceps. It is unclear from this case report, how long she had been pitching and what volume she had been pitching. She had not returned to play 21 months post-operation.

To summarize, the injuries associated with the windmill motion appear to be overuse injuries (2–6). Meyers et al substantiate the concept of over training and its role in injuries.[4] As noted previously, the delivery is thought to be the crucial moment where the possibility of injury is the highest (3,5).

PREVENTION AND TREATMENT

Prevention

Recognizing that proper mechanics is the primary key to preventing injury, the position of the pitching arm is significant at the beginning of the delivery or just after the 12 oclock position (3,5,8,10). Increased stress to the shoulder occurs if the arm is out of the body plane or has progressed too far into the downswing (5,10). A straight arm at ball release amplifies the centrifugal forces, thereby increasing the stress on the proximal joints (3,10). In a report to the coaches, Werner et al detailed causes resulting in stress on the shoulder along with factors that influence performance (10). Many of these factors overlap. Further recommendations from their findings included a slight bend in the elbow (approximately 20 degrees) at ball release and no more than 35 degrees bend in the stride knee when the stride foot contacts. They further identify the position of the hips at ball release critical in decreasing the load on the shoulder. These experts advise closing the hips to 45 degrees or more upon ball release,[10] remarking that an increase in this angle increase the stress on the shoulder.

In their study of the muscle activities associated with the windmill pitch, Maffet et al speculate, "weakness or asynchronous contraction of these muscles can contribute to increased stress and stretching of the anterior shoulder capsule." Specifically, "a weak, deconditioned, or injured serratus anterior muscle can lead to asynchrony of motion between the scapula and the glenohumeral joint, thereby increasing the stress on the static stabilizers of the shoulder" (5). The concept of scapular dysfunction is not new. Many agree that the scapulothoracic joint is the keystone to proper shoulder function (13) making scapular stabilization exercises a necessity to optimal performance. In addition, with the increasing incidence of multidirectional instability, as noted by Meister and decreased proprioception in female softball players, as studied by Dover et al, proprioceptive exercises enhance the neuromuscular control thereby improving the dynamic stability (13,15).

Treatment

Treatment begins with prevention and goes through conditioning. After proper assessment of an athlete's strengths and weaknesses, training programs should be devised to meet the individual's needs. Sport-specific training focuses on the actions or movements necessary to perform the act and to the muscles most susceptible to injury (8). Softball is an anaerobic activity requiring short bursts of energy, resulting in power, acceleration and speed (24). This is not to discount the benefit of an aerobic base. Periodization is an important tool to enhance the exercise program. It is a method of varying the focus of the exercise program to match the stage of the season: pre-season, in-season and off-season. For example, aerobic training would be emphasized in the off-season while strength training would be the focus in pre-season. During the season, maintenance of strength and endurance is the strategy (24).

For the pitcher, motions that contribute to the windmill action include: shoulder flexion, internal rotation of the shoulder, elbow flexion, forearm pronation, wrist flexion in addition to hip extension and rotation, and knee extension of the pivoting leg (8). Strength and flexibility training is the foundation. Equally important is conditioning of the antagonist muscle, which decreases the likelihood of muscular imbalances. Conditioning the agonist in the eccentric phase of contraction is also essential for overall muscular strength and protecting the muscles from deceleration injuries. One study by Pugh et al demonstrated a high relationship between arm strength and ball speed (25). Lower body strength and core stability are likely important factors.

Research on the treatment of existing conditions is limited. A recent study published in 2003 investigated various therapeutic measures on shoulder strength and muscle soreness in baseball after pitching (26). Recommendations included ice therapy followed by light shoulder exercise to decrease muscle soreness and improve muscle strength post treatment.

Another alternative, Active Release Technique (ART), is a conservative manual therapy that addresses problems with muscles, tendons, ligaments, fascia and nerves.[16] Buchberger notes "several papers discuss the successful application of Active Release Technique for the treatment of overuse and repetitive strain-type injuries in the shoulder" (27). He states that muscle inhibition can result from the limited motion from adhesions of adjacent tissues. Muscles become shorter and weaker, tension on tendons result in tendonitis, and nerves can become trapped. The consequence is reduced range of motion, loss of strength, and pain. With nerve entrapments, tingling, numbness, and weakness are common (16).

CONCLUSION

There is a complex sequence of actions necessary to achieve the fast-pitch motion effectively. Successful performance of this movement requires proper biomechanics, strength and coordination. Investigators have demonstrated that the stresses to the shoulder joint, while performing a windmill pitch, approximate that of the overhand throw.

The combination of high volume of windmill pitching, with little rest period in between, results in a significant number of time loss and over-use injuries in youth. In addition to proper technique, conditioning is an essential factor to injury prevention. Many agree that the chance of injury is minimized when proper biomechanics are utilized. Coupled with a well-designed conditioning schedule, this should be the first step in preventing. A second step could be regulation of the frequency and volume of pitching in youth fast-pitch. Further investigations into these factors, in addition to pitch type, need to be addressed. Further studies, such as those utilizing ART, traditional strength and flexibility training, and proprioceptive training, are warranted.

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